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Yield Response of Head Lettuce ('Lactuca sativa' L.) to Ozone

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16. ABSTRACT

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YIELD RESPONSE OF HEAD LETTUCE (*LACTUCA SATIVA* L.) TO OZONE

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TEMPLE P. J., TAYLOR O. C. and BENOIT L. F. *Yield response of head lettuce* (Lactuca sativa *L.*) *to ozone*. ENVIRONMENTAL AND EXPERIMENTAL BOTANY **26,** 53–58, 1986.—Head lettuce (*Lactuca sativa* L. cv 'Empire') was grown in the field and exposed in open-top chambers to proportional increments of ozone (O_3) from full charcoal filtration (CF) to twice ambient O_3 concentrations (NF × 2.0). Severe foliar injury developed on young plants exposed to O_3 concentrations 1.7 and 2.0 times greater than ambient (seasonal 7 hr means of 0.104 and 0.128 ppm, respectively). These exposure levels also reduced total head weight 13 and 35%, respectively, compared with CF plants. Marketable-sized head weight was reduced 21 and 80%, respectively. Plants in O_3-added chambers matured 2–3 weeks later than plants in low O_3 chambers. Regression analysis of yield data indicated that the threshold for significant yield reduction of head weight was >0.083 ppm (seasonal 7-hr O_3 mean).

INTRODUCTION

LETTUCE (*Lactuca sativa* L.) was among the first species identified as being highly susceptible to oxidant injury in Southern California.[6,8] In these early observations silvering, glazing and/or bronzing were reported on the lower (abaxial) leaf surface of the 'Romaine' cultivar of lettuce. This injury, later attributed to peroxyacetyl nitrate (PAN)[14] was aesthetically displeasing to the consumer and frequently rendered the crop unmarketable.

Ozone (O_3) injury symptoms on 'Romaine' and other cultivars was later described as chlorotic and necrotic upper surface fleck which became bifacial collapse as the intensity of injury increased.[13] In some instances the injury was expressed as chlorosis and cell clearing on the lower leaf surface. REINERT *et al.*[13] exposed 8 lettuce cultivars to high concentrations of O_3 (0.7 ppm for short periods, 1.5 hr max) to determine relative susceptibility and identify injury symptom expressions. They found that 'Romaine' and 'Black Seed Simpson' cultivars were significantly less susceptible to O_3 than the other cultivars and found dark green 'Boston' to be most susceptible.

OSHIMA[9] used 'Prize Head' and dark green 'Boston' cultivars of lettuce to determine the effects of field exposures and of fumigations with PAN and O_3 on expressions of leaf injury and growth. He concluded that 'Prize Head' was resistant to both O_3 and PAN at all stages of growth and elected to continue his study with dark green 'Boston' which was sensitive to the oxidants. OSHIMA[9] reported that O_3 in concentrations of 0.2 and 0.3 ppm for about 7% of the growing season reduced the overall size of dark green 'Boston' plants. OSHIMA[10] found that fumigation for 6% of the season with 0.15 ppm and with 0.25 ppm O_3 produced foliage injury and reduced fresh weight of the dark green 'Boston' cultivar. A preliminary open-top chamber experiment conducted in 1980 with 'Empire' head lettuce suggested that yield could be reduced at elevated concentrations of O_3, but no

dose–response functions could be constructed from this study.[4] Despite the obvious susceptibility of lettuce to foliar injury from PAN and to a lesser degree to O_3, relatively little is known about the long-term effects of these oxidants on growth and yield of the crop.

California leads the nation in production of lettuce with 69% of the United States market in 1983. Total value of the crop was $542 million.[2] Lettuce is grown year-round in Southern California, and fall production is concentrated in areas of potentially elevated ambient O_3 such as the Southern San Joaquin Valley.[15]

This experiment was conducted as part of the National Crop Loss Assessment Network (NCLAN). The primary objective of NCLAN is to develop dose–response relationships between yield of major crop plants and exposure to O_3 and other air pollutants and to apply these data to a model of farm production to assess the overall impacts of air pollution on agriculture. The objective of this experiment was to develop a dose–response function for the effects of O_3 on growth and yield of head lettuce.

MATERIALS AND METHODS

The experiment was conducted at the USDA Cotton Research Station in the San Joaquin Valley of California. The soil is a deep Wasco sandy loam (coarse-loamy, mixed, non-acid, thermic, Xeric Torriorthents) with some variation in percent sand. Pre- and post-season soil sampling indicated that all measured soil parameters were within optimum range for field crop production. A cover of cowpeas (*Vigna sinensis* L.) was rototilled into the plot area to a depth of 30 cm on 30 July 1983. Superphosphate (0-25-0-10S) was spread evenly over the field at a rate of 140 kgP/ha and the area was treated with Balan (preemergence herbicide) at a rate of 7 l/ha. Plots were fertilized with 36 kg/ha of nitrate (20-10-10) and four flat-topped beds each 5.16 m long and 56 cm wide were formed on 100 cm centers in each of 30 plots. Two rows of crisp-head lettuce (*L. sativa* var *capitata* cv 'Empire') were seeded 30.5 cm apart on each bed on 16 August. The site was sprinkle-irrigated on 18 August and later as needed until emergence. Plants were later thinned or transplanted as needed to obtain a uniform stand of 5–6 plants per meter-row. Plants were treated with Orthene (1.5 kg/ha), thuricide (4.9 l/ha), and Sevin (80 ml/ha) weekly to control lepidopteran larvae.

Irrometers were installed in each plot at 30 cm depth. Irrigation water was applied before soil moisture reached −300 mb and before furrow bottoms became completely dry. Plots were furrow-irrigated through a manifold system that delivered approximately 1 ha-cm of water per hour. All plots received the same amount of irrigation throughout the season. Total precipitation plus irrigation amounted to 58.4 cm of water for the season.

Ozone treatments and monitoring

Seven O_3 treatments, each replicated four times, were assigned to 28 plots in a completely random experimental design, and 24 open-top chambers[3] were placed on the lettuce plots on 31 August, when plants were at the 1–2 true leaf stage. Chamber blowers were operated by time clock and operated from 0600 to 2000 daily. The six chamber treatments were charcoal-filtered (CF); half-filtered (NF × 0.50); non-filtered (NF); and three treatments in which O_3 was added in proportion to ambient O_3 concentration: NF × 1.3, NF × 1.7, and NF × 2.0. The four chamberless plots were used as ambient air (AA) controls. Ozone was added from 0900 to 1600 daily from 6 September to 28 October 1983. Ozone dispensing and monitoring, and data acquisition systems were the same as those previously described.[14] Ozone monitors were calibrated weekly with a transfer standard certified by the California Air Resources Board. Sample line losses of O_3 averaged $<2\%$.

Plant growth and harvest

Lettuce seedlings emerged on 22 August, and plants were at the 1–2 true leaf stage when chambers were put in place on 31 August. Chambers and AA plots were examined daily for pests, diseases, O_3 injury symptoms and plant development during the exposure. Chambers and AA plots were harvested on 3 November, when plants in NF chambers were mature. Separate 1 m-row samples were taken from each of four quadrants in the chamber or AA plot. Each plant was cut at ground level, weighed, trimmed of

wrapper leaves, and re-weighed. Size and quality[1] of each head was also recorded. Commercial size heads were graded for quality by a state agricultural inspector, and weights were taken on composite "24"-head (commercial size) boxes from each O_3 treatment.

Yield data were analyzed by analysis of variance using a completely randomized design. Dose–response relationships between seasonal 7-hr O_3 means and harvest data for each treatment were analyzed by linear multiple regression and non-linear regression using the Weibull model.[12] Open (AA) plots were not included in the regression analysis.

RESULTS

Air quality

Seasonal 7-hr (0900–1600) ambient O_3 concentration averaged 0.054 ppm during the exposure period for lettuce, 6 September to 28 October 1983. Seasonal fluctuations in 7- and 24-hr ambient O_3 concentrations are shown in Fig. 1. Mean seasonal 7-hr O_3 concentrations for the six chamber treatments were: CF = 0.021 ppm; NF × 0.5 = 0.038 ppm; NF = 0.052 ppm; NF × 1.3 = 0.083 ppm; NF × 1.7 = 0.104 ppm; NF × 2.0 = 0.128 ppm (Table 1). Other expressions of O_3 exposure, including highest 1-hr concentration, highest 7-hr concentration, and mean daily maximum hourly concentration, are given in Table 1.

Plant responses

On 7 September, after 2 days of O_3 additions, slight interveinal chlorosis and bronzing were noted in the NF × 2.0 treatments. Similar symptoms were observed in NF × 1.3 and NF × 1.7 treatments by 12 September and symptom development increased in intensity with increasing exposure to O_3 until plants began to mature. No O_3 injury symptoms were observed in other O_3 treatments. Plants in NF × 2.0 chambers were severely reduced in size at harvest and leaves appeared more elongated than those in other treatments. Head formation in NF × 2.0 chambers was delayed 2–3 weeks in comparison with CF and NF chambers.

Total head weight, and weight and number of marketable ("24"-size) lettuce heads per treatment are given in Table 2. Ozone reduced total head weight and number of marketable heads in the NF × 1.7 and NF × 2.0 treatments; that is, when seasonal 7-hr O_3 concentration exceeded 0.083 ppm. Biomass was reduced 12.9% in the NF

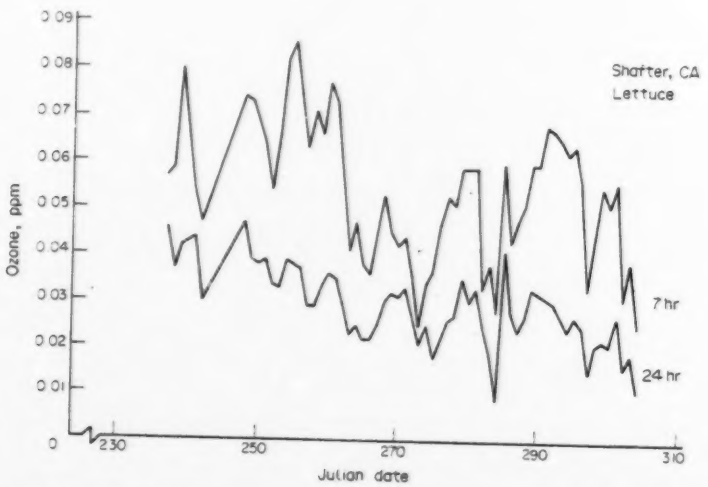

FIG. 1. Daily 7- and 24-hr mean ambient O_3 concentrations during lettuce season 31 August to 31 October 1983.

Table 1. Summary of O_3 concentrations during exposure of 'Empire' lettuce at Shafter, CA, 6 September to 28 October 1983; all data in ppm

	7-hr means (0900–1600)		1-hr means		
Treatment	Seasonal	Maximum	Maximum	Second maximum	Mean seasonal
CF	0.021	0.034	0.047	0.040	0.027
NF × 0.5	0.038	0.059	0.066	0.065	0.046
NF	0.052	0.083	0.092	0.090	0.062
NF × 1.3	0.083	0.136	0.157	0.148	0.102
NF × 1.7	0.104	0.172	0.197	0.190	0.128
NF × 2.0	0.128	0.205	0.230	0.216	0.157
AA	0.054	0.086	0.095	0.093	0.065

Table 2. Yield data for field grown 'Empire' head lettuce exposed to O_3 in open-top chambers in Shafter, CA from 6 September to 28 October 1983; four replicates per treatment

Treatment	Total head weight (g/m-row)	Mean head weight (g)	No. "24"* heads/m-row	Weight "24" heads/m-row	No. "24" boxes†
CF	6961	732	12	3037	2.0
NF × 0.5	7118	764	12	3072	2.0
NF	7230	815	13	3210	2.2
NF × 1.3	7505	847	12.5	3383	2.1
NF × 1.7	6063	663	9.5	2402	1.6
NF × 2.0	4533	466	2.5	604	0.4
AA	7465	829	13	3780	2.2

*Size "24" heads are commercial, marketable size.
† Mean number of boxes of size "24" heads per treatment.

Table 3. Analysis of variance mean squares for 'Empire' lettuce exposed to O_3 in open-top chambers at Shafter, CA 1983

Source of variation	d.f.	Total head weight × 10^5	Weight per head × 10^3	Weight of "24" heads × 10^5	Number of "24" heads
Ozone	5	49.36*	76.15*	41.97†	64.00†
Error	18	3.51	4.32	7.29	13.47
C.V.		9.0%	9.2%	33.1%	35.8%

*Significant at 1% level.
† Significant at 0.1% level.

× 1.7 treatment and 34.9% in the NF × 2.0 treatments, compared with CF chambers. Number of commercial ("24"-size) heads was reduced 20.9 and 80.1%, respectively. Total head weight and mean head weight from AA plots averaged 3% greater than NF chambers, but "24"-size head weight was 15% less in NF chambers compared with AA plots. Ozone effect on yield was highly statistically significant (Table 3).

Regression analysis of yield data indicated that the least squares best fit model of yield responses to mean seasonal 7-hr O_3 concentrations was piece-wise linear regression. However, the slope of the yield response curve below the break point of 0.083 ppm did not differ significantly from 0. Thus, the linear regression models for total head weight and "24"-size head weight were "plateau-linear" (Table 4). The Weibull model[12] was also fit to these data. The response curve generated by fitting the Weibull model was similar to that of the plateau-linear model (Fig. 2). Estimates of Weibull parameters and their standard errors are given in Table 4.

Table 4. Best-fit regression equation for total head weight and "24" size (commercial) head weight of 'Empire' lettuce exposed to O_3 in open-top chambers, Shafter, CA, August to October 1983. Y = g/m-row; X = mean seasonal 7-hr O_3 concentration

(A) Plateau-linear model
Total head weight
$Y = 7203 - b_1[65616\ (O_3 - 0.082)]$ $R^2 = 0.78$
S.E. = ±138 ±9263
Weight of "24"-size heads
$Y = 3113 - b_1[62682\ (O_3 - 0.082)]$ $R^2 = 0.62$
S.E. = ±189 ±13103
if $O_3 < 0.082$; $b_1 = 0$
if $O_3 > 0.082$; $b_1 = 1$

(B) Weibull model
Total head weight
$Y = 7205.3 \exp - (O_3/0.144)^{6.219}$
S.E. = α = ±175.4
σ = ±0.0067
C = ±1.876
Weight of "24"-size heads
$Y = 3187 \exp - (O_3/0.122)^{8.837}$
S.E. = α = ±239.4
σ = ±0.0056
C = ±4.283

DISCUSSION

Exposure to O_3 produced visible foliar injury symptoms and reduced lettuce yield in this experiment, although significant reductions in head weight developed only after exposure to O_3 concentrations higher than ambient in the San Joaquin Valley in 1983. Foliar injury symptoms became apparent 2–6 days after O_3 exposures began, but injury development became progressively less as the plants matured. Foliar injury was confined to basal or "wrapper" leaves. As these were discarded when heads were trimmed at harvest, injury symptoms did not impair marketability of the lettuce crop. The contrasts with field[11] and greenhouse[10] exposures of leaf lettuce cultivars in which severe foliar injury symptoms reduced aesthetic appearance of the crop and thus reduced marketability. OSHIMA[10] exposed 'Boston' leaf lettuce to O_3 at 0.15 and 0.25 ppm, 6 hr/day, 1.5 times/week for 4 weeks, equivalent to seasonal 7 hr means of 0.033 and 0.055 ppm, respectively. Visible injury developed at the lower concentration but fresh weight at harvest was not significantly different from control. At the higher concentration foliar injury was greater and plant fresh weight was significantly lower than control. In our experiment, significant head weight reduction was not observed at O_3

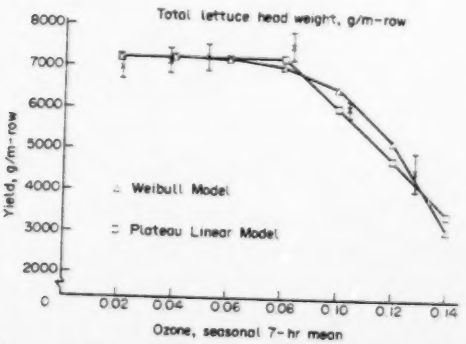

FIG. 2. Dose–response curves of total head weight of 'Empire' lettuce exposed to O_3 in open-top chambers. Data points are mean treatment yields ± 1 S.E. of the mean.

concentrations below a seasonal 7 hr mean of 0.083 ppm. Although it has been generally observed that plants grown in the field are less susceptible to O_3 effects than greenhouse-grown material,[7] these results suggest that head lettuce may be more resistant to O_3 than leaf lettuce cultivars.

Exposure to O_3 also showed maturation of plants in this experiment. Head formation in O_3-added chambers was delayed 2–3 weeks in comparison with CF and NF chambers. Delay in head formation could have economic consequences for commercial lettuce growers, most of whom sell their crop on contract to large packing houses. If the grower fails to deliver his crop by a specified date the contract could be abrogated or renegotiated at a greatly reduced price per box of lettuce. If exposure to O_3 delayed head formation beyond the anticipated harvest date then the economic return to the grower could be severely reduced, even though ultimate crop yield may be only slightly reduced.[5] The results of this experiment suggest that high O_3 concentrations can increase the risk of economic losses to commercial lettuce growers not only by direct loss in crop yield but also by unanticipated shifts in harvest date.

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